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EXPLORATORY ANALYSIS OF CONDENSATE STABILIZATION IN A TUBE HEAT EXCHANGER

Islomov A.N.
Target base doctoral student, Bukhara Institute of Engineering and Technology
Abduraxmonov O.R.
Doctor of technical sciences, professor, Bukhara Institute of Engineering and Technology

Abstract: Studying the physical-chemical properties of raw materials involved in the management of oil and gas processing processes is one of the main issues. This article provides information on the physico-chemical properties of the raw condensate liquid and steam used in the heat exchange device, the calculation of the device and the heat transfer coefficients of the condensate and its steam.
Key words: density, viscosity, hydrometer, viscometer, areometric and pycnometric method, average temperature, equivalent diameter, criteria, heat transfer coefficient.

Introduction. The more accurately the calculation of the physical properties of the substance using the experimental method or empirical formulas is calculated, the more accurately the results of technological calculations in the design of technological equipment are created in the processing of raw materials. Calculation and design of devices for simultaneous heating of condensate raw materials and separation of their fractions requires knowledge of physical–chemical and thermal–physical properties of the investigated substances.

The main part. In laboratory conditions, the density of condensate liquids (GOST 3900-85) was determined in two different ways using areometric and pycnometric methods. Since the temperature of the technological processes carried out in the shell-and-tube heat exchanger selected as a research object is 120÷150 °C, it is necessary to calculate the physical quantities of the condensate up to a temperature of 150 °C. For this reason, the densities of the studied hydrocarbons at temperatures of 20÷150 °C are determined by empirical formulas using mathematical expressions.

Relative density of oil and gas products in oil and gas processing ρ_4^{20} dimensionless value is used, which is the ratio of the density of oil at 20 °C to the density of water at 4 °C. Abroad, the standard temperature for oil and water is 60 °F (15.5 °C). In the temperature range of 20÷150 oC, the density of oil fraction distillate D.I. Mendeleev's formula is used. The error rate of this formula is 5-8% [2]:

$$\rho_4^t = \rho_4^{20} - a(t-20) \quad (2)$$

here ρ_4^t - density of raw material at a given temperature and ρ_4^{20} - 20 ° C relative density equal to the ratio of the density of oil to the density of water at 4 °C; a 1 °C temperature correction indicator [GOST 3900-47] and ρ_4^{20} depends on the size [3, 4]. Abroad, the standard temperature and specific gravity for oil and water is 60 °F (15.5 °C) ρ_{15}^{15} is determined by.

$$\rho_{15}^{15} = \rho_4^{20} + \frac{0,0035}{\rho_4^{20}} \quad \text{or} \quad \rho_{15}^{15} = \rho_4^{20} + 5a \quad (3)$$

At temperatures from 50 °C to 300 °C, it was calculated according to A.K. Manovyan's equation [5]:

$$\rho_4^t = 1000\rho_4^{20} - \frac{0,58}{\rho_4^{20}}(t-20) - \left[\frac{t-1200(\rho_4^{20}-0,68)}{1000}\right]\cdot(t-20) \quad (4)$$

The results of calculating the density of condensate at temperatures of 20÷150 °C are presented in Table 1.

Table 1

Liquid hydrocarbon unstable condensate at temperatures of 20÷150 °C

density calculation results

t, °C	**20**	**30**	**40**	**50**	**60**	**70**	**80**
ρ, kg/m³	757	749	740	732	724	715	707
t, °C	**90**	**100**	**110**	**120**	**130**	**140**	**150**
ρ, kg/m³	699	690	682	674	666	657	649

Also, the composition of vaporous hydrocarbon released from the valve installed in the cover part of the shell-and-tube heat exchanger up to a temperature of 50 °C was studied in laboratory conditions. Physico-chemical and thermal-physical properties of each hydrocarbon in vaporous hydrocarbons based on the rule of additivity (6), the density, viscosity, thermal conductivity coefficients of unstable condensate vapor were calculated and the density of unstable condensate vapor at a temperature of 25÷50 °C the results are presented in Table 2.
Table 2
Unstable condensate steam at 25÷50 °C

density calculation results

t, °C	**25**	**30**	**35**	**40**	**45**	**50**
ρ, kg/m³	0,431	0,420	0,392	0,371	0,360	0,351

Viscosity. Viscosity is the resistance of one layer of liquid to another layer. Viscosity properties of various fluids are evaluated by dynamic and kinematic viscosity coefficients.
ν - coefficient of kinematic viscosity, unit, mm^2/s;
μ - dynamic viscosity coefficient, unit, Pa·s.
Fluids that obey Newton's law of internal friction (for example, water, alcohol, benzene) are called Newtonian fluids. Oil, colloidal solutions, oil paints, tars, lubricating oils used at low temperatures are not Newtonian fluids; such liquids are called non-eutonic liquids [7].
A glass viscometer VPJ-4 with serial number 2129 was used to measure the kinematic viscosity of distillates (capillary diameter d = 0.82 mm, instrument constant K = 0.02880 mm^2/s^2). The experiments were carried out in accordance with the GOST 33-2000 (ISO 3104 94) standard.
Experiments on measuring the kinematic viscosity of the studied hydrocarbon samples were initially conducted in a bench setup at temperatures from 20 to 98 °C, limited by the boiling point of water in the bench thermostat. Then, the kinematic viscosity of the oil and gas fraction at a temperature higher than 98 °C (up to 180 °C) corresponding to the operating conditions, that is, at any temperature, was calculated using the Reynolds-Filonov formula [8]:

$$\nu = \nu_o e^{-k\cdot(T-T_o)} \qquad (5)$$

here ν_o - T_o = 293,15 K oil viscosity at; e = 2,71 - the base of the natural logarithm;T - temperature at which viscosity is determined; k - viscogram kurtosis coefficient
$K = \ln(\nu_o/\nu)/(T-T_o)$ is determined using.
Based on these determined physical and chemical properties, the heat transfer coefficients of condensate and its steam are determined based on the calculation of the heat exchange device [9].
Heating agent unstable condensate:
G = 25 tons / hour; $t_1 = 25\ ^0C$; $t_2 = 70\ ^0C$
Heating agent unstable condensate:
G = 25 tons / hour; $t_1 = 170\ ^0C$; $t_2 = 90\ ^0C$
Heat load of the device:

$Q = G_1 \cdot c_p \cdot (t_2 - t_1) = \frac{25000}{3600} \cdot 2190 \cdot (70-25) = 684375$ Vt (6)

Average temperature difference:

The average temperature difference is found as the arithmetic mean temperature:

$\Delta t_{av} = \frac{80+45}{2} = 62{,}5\ ^0C$ (7)

$\Delta t_{av} = 62{,}5\ ^0C$ at $K_{tax} = 350$ Vt/(m^2·K).

The required surface for the approximate heat exchange load is found:

$F_{tax} = \frac{Q}{K \cdot \Delta t_{av}} = \frac{671875}{350 \cdot 62{,}5} = 31\ m^2$ (8)

$F = 31\ m^2$; $D = 400$ mm; $d = 25x2$ mm; $n = 100$; $z = 2$; $l = 3$ m;

Average temperature for stable condensate:

$t_{av} = \frac{170+90}{2} = 130\ ^oC$

Average mass velocity of stable condensate:

$V_1 = \frac{G_1}{\rho_1} = \frac{6{,}95}{666} = 0{,}0104\ m^3/s$; $w_1 = \frac{V}{S} = \frac{0{,}01}{0{,}030} = 0{,}35$ m/s (9)

To determine the mode of operation of stable condensate, the equivalent diameter of the inter-pipe space is determined [10]:

$d_e = \frac{4f_{mt}}{\Omega} = \frac{D^2 - nd_t^2}{ndt} = \frac{0{,}4^2 - 100 \cdot 0{,}025^2}{100 \cdot 0{,}025} = 0{,}039\ m$ (10)

Determination of Reynolds number:

$Re_1 = \frac{wd\rho}{\mu} = \frac{0{,}35 \cdot 0{,}039 \cdot 666}{0{,}09 \cdot 10^{-3}} = 101010$ (turbulent regime) (11)

Determination of Prandant's number:

$Pr_1 = \frac{c \cdot \mu}{\lambda} = \frac{2190 \cdot 0{,}09 \cdot 10^{-3}}{0{,}15506} = 1{,}27$ (12)

Determination of Nusselt number:

$Nu = 0{,}008 \cdot Re^{0{,}8} \cdot Pr^{0{,}43} = 0{,}008 \cdot 101010^{0{,}8} \cdot 1{,}27^{0{,}43} = 89{,}4$ (13)

Heat transfer coefficient to the pipe wall α_1 calculate:

$\alpha_1 = \frac{Nu \cdot \lambda}{d} = \frac{89{,}4 \cdot 0{,}15506}{0{,}039} = 355{,}45$ Vt/(m^2·K) (14)

As the heating agent is heated inside the unstable condensate shell-and-tube heat exchanger, it forms condensate vapor in the inner tubes. In order to determine the thermal-physical properties of each substance in the condensate vapor, the rule of additivity (the relationship between substance transfer and substance release coefficients) is assumed to establish an equilibrium state on the phase-separating surface. Such a state means that there is no resistance to the passage of substance through the phase-separating boundary. As a result, the rule of additivity of phase resistances is derived) determined based on (85).

Heating agent consumption G = 25 tons/hour. Based on the experiment, the mole ratio of liquid and vapor hydrocarbons at a temperature of 50 ^{0}C is 80:20. In this way, their consumption is found as follows:

25·80 = 20 tons/hour of liquid hydrocarbon,

25·0.21 = 5 tons/hour of vaporous hydrocarbon.

Heat content of condensate:

$Q = G_1 \cdot c_p \cdot (t_2 - t_1) = \frac{20000}{3600} \cdot 2600 \cdot (70-25) = 655200$ Vt

Average mass velocity of condensate: $\omega = 0{,}22$ m/s

For condensate hydrocarbon, the criteria are equal to: [11, 12] :

$Re = 7074{,}4$; $Pr_1 = 6{,}6$; $Nu = 21{,}7$

Calculation of heat transfer coefficient:

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$a_2^{'} = \frac{Nu_f \cdot \lambda}{d_{ich}} = \frac{21,7 \cdot 0,1602}{0,021} = 165,5$ Vt/(m^2·K)

Heat content of condensate steam:

$t_{o\ av} = \frac{25+50}{2} = 37,5$ °C

$Q = G_1 \cdot c_p \cdot (t_2 - t_1) = \frac{5000}{3600} \cdot 170 \cdot (50-25) = 5902,8$ Vt

Average mass velocity of condensate steam:

$\omega = \frac{4G}{\pi \cdot d^2 \cdot n \cdot \rho} = \frac{4 \cdot 1,39}{3,14 \cdot 0,025^2 \cdot 100 \cdot 0,35} = 80,95$ m/s

The criteria for a vaporous hydrocarbon are:
$Re = 416654,5$; $Pr_l = 0,048$; $Nu = 67,9$
Calculation of the coefficient of heat transfer from a vaporous hydrocarbon to the wall:

$$a_2^{''} = 19,4 \text{ Vt/(m}^2\text{·K)} \quad (15)$$

Determination of the actual heat transfer coefficient:
Wall thickness δ = 0,002 mm, (stal 45) λ = 50,2 Vt/(m·k)

$$K_x = \frac{1}{\frac{1}{\alpha_1}+\frac{\delta}{\lambda}+\frac{1}{\alpha_2}} = \frac{1}{\frac{1}{355,45}+\frac{0,002}{50,2}+\frac{1}{(19,4+165,5)}} = 121,3 \text{ Vt/m}^2\text{·K} \quad (16)$$

Heat exchange surface:

$$F_x = \frac{Q}{K \cdot \Delta t_{o'r}} = \frac{684375}{121,3 \cdot 62,5} \approx 91 \text{ m}^2 \quad (17)$$

Table 3
Condensate and its steam at different temperatures
the difference between heat transfer coefficients

temperature, ^{0}C	$\alpha_{2(suyuq)}$	$\alpha_{2(bug')}$	$\Delta\alpha_2$
30	190,3	7,8	182,5
35	177,9	12,6	165,3
40	171,7	15,5	156,2
45	167,6	17,5	150,1
50	165,5	19,4	146,1

Figure 1
Condensate and its steam at different temperatures
an image of heat transfer coefficients

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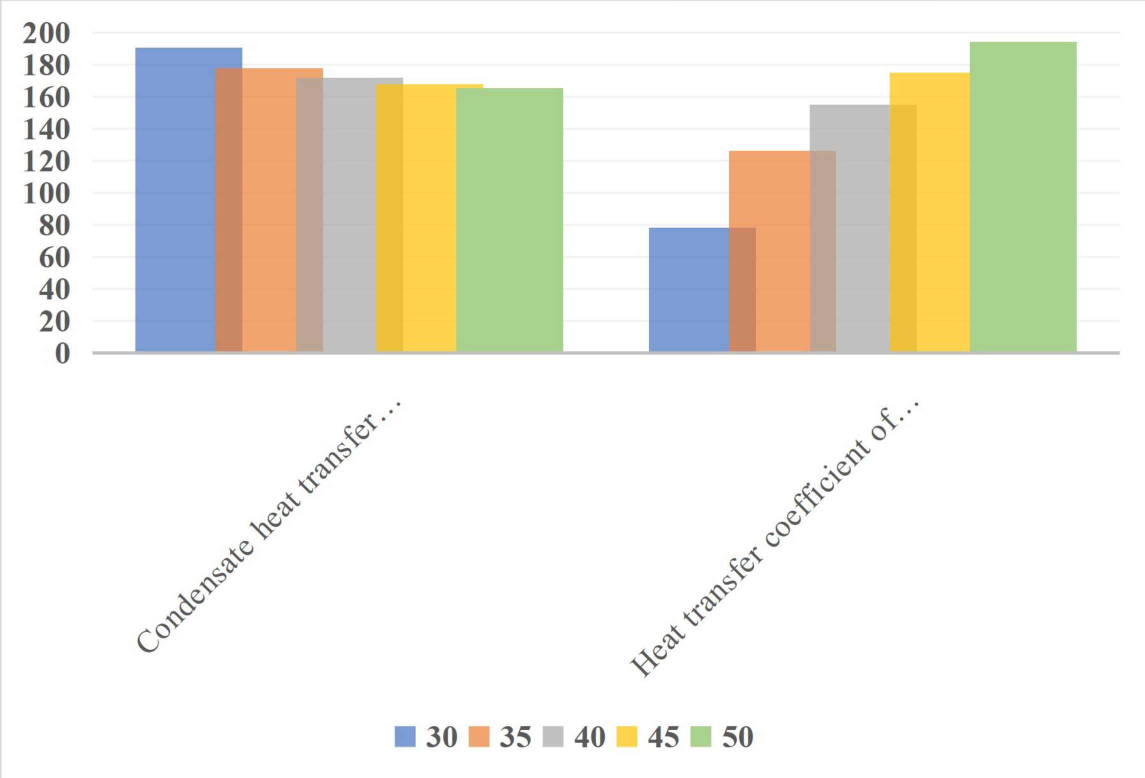

Conclusion. During the experiment, the density and kinematic viscosity of the physico-chemical properties of the condensate and condensate steam formed by heating the unstable condensate in a heat exchanger in the temperature range of 25÷50 oC were studied in laboratory conditions. By determining the physico-chemical properties of the substance, the heat transfer coefficient of the condensate and its steam was determined.

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